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Effect of a Body Model on Performance in a Virtual Environment Search Task

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The U.S. Army Research Institute is investigating requirements for using Virtual Environments (VE) in training dismounted soldiers. This experiment investigated full-body representation (generic) versus a hand-linked pointer on movement performance in an office building interior during a search task. The search task was used as a representative dismounted soldier activity in urban environments.

The VE used a biocular Head-Mounted-Display (HMD) with head-coupled and body-referenced movement control. Sensors enabled participants to "walk" through the VE while performing the search task in six repeated trials. Movement time and number of collisions during discrete phases of the search task revealed no significant differences found between full-body and pointer representations, although significant improvement was found over repeated trials. Field of View is discussed as a possible intervening aspect.

A Simulator Sickness Questionnaire (SSQ) was administered before, during, immediately after the experiment, and after a recovery period. Significant changes in the SSQ were found over the course of the experiment, but were not related to the body representation condition. The results indicate a rapid onset of symptoms followed by some adaptation to the VE, and rapid recovery. The Immersive Tendencies Questionnaire administered pre-experiment, and the Presence Questionnaire administered post-experiment, were not significantly related to the body representation conditions.

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Education and Training Technology

FOREWORD

The U.S. Army has made a substantial commitment to the use of networked simulations for training, readiness, concept development, and test and evaluation. The Close Combat Tactical Trainer (CCTT) is designed to provide realistic training and rehearsal for large combined arms groups of vehicles and major weapon systems. The system represents dismounted soldier activities in an awkward manner, and is not intended to directly train dismounted soldiers. Virtual Environment (VE) technology, which includes head-mounted visual displays with tracking devices for limbs and individual weapons, has the potential to provide a more immersive, person-centered simulation and training capability for dismounted soldiers. One research challenge is identifying and quantifying the effects of VE system characteristics and features on learning, skill acquisition, retention, and transfer of U.S. Army tasks.

This report describes an experiment in an ongoing program of research addressing the use of VE technology for training dismounted soldiers. The experiment investigated the use of self-representation (an image of a generic body) in a VE on movement during a search task. Self-representation was expected to improve awareness of orientation in the VE and the ability to move through the VE successfully. It failed to show improvement in this experiment, possibly due to limitations in the visual display devices used. The experiment also investigated the onset and recovery from simulator sickness symptoms. The results from participants completing the experiment indicate that symptoms level off early in the experience and recovery is relatively quick afterward. The findings from this research can be used to recommend VE characteristics and methods that should be incorporated in VE training or rehearsal systems.

The U.S. Army Research Institute, Simulator Systems Research Unit, conducts research with the goal of providing information that will improve the effectiveness of training simulators and simulations. The work described here is a part of ARI Research Task 2111, VIRTUE - Virtual Environments for Combat Training and Mission Rehearsal.

Zita M. Simutis

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EFFECT OF A BODY MODEL ON PERFORMANCE IN A VIRTUAL ENVIRONMENT SEARCH TASK

EXECUTIVE SUMMARY

Research Requirement:

The U.S. Army is committed to using distributed interactive simulations for mission planning, training, rehearsal, concept development, and testing and evaluation. Current systems are designed to provide training for soldiers fighting from vehicles, but are not designed to provide realistic training for dismounted infantry. Virtual Environment (VE) technology provides a new way to simulate real world activities for individual dismounted soldiers. This technology may allow the U.S. Army to cost-effectively conduct planning, training, and rehearsal activities for both individual and collective dismounted soldier tasks. Basic to these simulations is the common context for individual combatants who need to move, observe, shoot, and communicate. Research on the effects of specific VE system characteristics can establish the benefits and problems of training and rehearsing complex activities and tasks using VE technology.

Procedure:

In this experiment, two groups of participants "moved" through VE representations of complex building interiors searching for designated targets. Both groups were equipped with a helmet-mounted biocular display and limb movement sensors. The Body Model group had a generic body that was visually represented and linked to the limb sensors, while the Pointer group was only provided a pointer representation linked to the hand sensor. Participants searched a set of virtual office rooms during each of six trials, with short breaks between trials and a long break between the third and fourth trial. The time required and number of collisions made during the search, physical acquisition of the target, and exit phases for each room in the set of offices was analyzed. Simulator Sickness Questionnaires (SSQ) were administered before the trials began, during the mid-experiment long break, immediately after the trials, and after a recovery period. Several additional questionnaires (biographical data, an Immersive Tendencies Questionnaire (ITQ), and a Presence Questionnaire (PQ)) were also administered either before or after the experiment.

Findings:

Having a Body Model did not affect the overall task time or collisions made during the trials, or the time to perform or number of collisions made during different phases of the task. Subjects did show significant improvement over trials, with decreased time and fewer collisions in later trials. The repeated SSQ administrations revealed a significant increase in SSQ scores between the beginning of the experiment and the middle break, no significant change between the middle administration and immediately after the experiment, and a significant decrease after a

recovery period. The post-recovery period SSQ average scores were not significantly different from the pre-experiment levels. This indicates a rapid onset of symptoms followed by some adaptation to the VE during the experiment, and rapid recovery to near-normal levels during the short post-experiment recovery period. No significant differences or correlations were found with the biographical information, the ITQ, or the PQ in relation to the body representation conditions.

Utilization of Findings:

The U. S. Army will employ VE technology for training, mission planning, rehearsal, and test and evaluation. Understanding the effect of different types of feedback during VE experiences will support cost-effective specification of VE configurations for different uses. These experimental results indicate that self-representation in VE systems does not directly improve movement adaptation that occurs during a search task. The finding that repeated short duration VE experiences can be adapted to and readily recovered from, in terms of simulator sickness symptom levels, indicates that VE trainees might not suffer from severe or cumulative simulator sickness problems during training.

EFFECT OF A BODY MODEL ON PERFORMANCE IN A VIRTUAL ENVIRONMENT SEARCH TASK

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EFFECT OF A BODY MODEL ON PERFORMANCE IN A VIRTUAL ENVIRONMENT SEARCH TASK

As computers have become more sophisticated and powerful, so have the graphical interface capabilities. The U.S. Army is using these capabilities in programs for vehicle-based combat training. These efforts originated in the Simulation Networking (SIMNET) program (DuBois, Birt, & Black, 1990), which evolved into the Close Combat Tactical Trainer (CCTT; Anton, Brooks, Gorman, Laird, & Miller, 1994), as a part of the Combined Arms Tactical Trainer (CATT) programs. These systems provide vehicle-based rehearsal and training to take place over networked simulators. They include individual soldier stations necessary for introducing the effects of dismounted soldiers into the vehicle-based training and rehearsal. What is not provided in these individual soldier stations is the capability for the dismounted infantry to train or rehearse dismounted soldier tasks.

Dismounted Soldiers and Simulation

One problem in the SIMNET vehicle simulation systems is spatial disorientation, which can affect performance in the simulation and possibly influence transfer performance detrimentally. Because there are limiting views and mixed cues, the vehicle commander may not always be aware of the correct vehicle orientation (Dr. Stephen Goldberg, personal communication, 1996), and therefore can give incorrect or inexact maneuver commands. These vehicle simulations are designed to less than 100% fidelity, presenting only limited visual displays without re-creating associated cues (e.g., motion) for position and orientation that are available in normal perception. For example, without receiving vestibular information (from physical movement) on the direction of vehicle movement, soldiers may confuse the direction of vehicle movement and orientation. Disjuncts like this can lead to two different deficits in the operator's spatial knowledge. Egocentric confusion in spatial knowledge is an incorrect conception of one or more landmark locations in relation to self. Exocentric confusion refers to the incorrect spatial understanding of objects in relation to one another. A related factor in spatial disorientation may be that the soldiers become confused about spatial orientation or local spatial knowledge as a result of the limited field of view (FOV) available in the simulation. Limited views of terrain presented in desktop training have been shown to impair performance in navigation tasks (Lickteig & Burnside, 1986). Performance decrements in the simulation can result from these perceptual confusions, and a potentially detrimental carryover to field performance could occur, if part of what was being learned was the spatial configuration of the operational environment.

The U.S. Army has an interest in effectively representing individual soldiers in these networked systems for Individual Combatant Simulation (ICS). The question is whether spatial orientation problems are likely to appear in these individual-based simulations. These simulations will use Virtual Environment (VE) technologies in an attempt to foster a more natural simulation interface. If the user is sitting and using a joystick for movement control, or

walking on a fixed-direction treadmill, vestibular feedback will not always agree with visual cues for movement. In these situations, the user will have a mismatch between normal visual cues and non-normal vestibular cues for understanding the space in which the task is being learned, practiced, or rehearsed. The mismatched cue set may impair performance, distort learning of the task, or detract from the transfer of task or situation context to the real world. Another related case is the nature of physical interaction required by the task. Interaction with a simulation that is coupled to appropriately spaced, body-linked hand movement should provide more egocentric orientation and proprioceptive feedback than a disembodied interaction (e.g., a joystick maneuvering a cursor, etc.) operating at non-physically linked distances (greater than arm length). It is possible that the low physical and functional fidelity of such representations would result in decreased learning, retention, and/or impaired transfer.

In our research program at the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), Simulator Systems Research Unit (SSRU), we have used several different interfaces to enable participants to move through VE databases. These include joysticks and spaceballs without any participant representation (Knerr, et al., 1994), buttons on the BOOM^{tm} display (e.g., Witmer et al, 1995), and an instrumented treadmill (e.g., Singer, Allen, McDonald, & Gildea, 1997). In all of these experiments, participants have had minor problems in maneuvering through the environments without colliding with objects. In particular, when moving within confined office spaces or through doorways, participants have had to be instructed and even trained in techniques for extricating themselves from collision states. (In VE systems, even a shallow angle collision results in a complete cessation of movement, and requires turning away or backing up to disengage the intersecting polygons before movement can be continued.)

These observations about possible confusions and the problems experienced by participants in our VE experiments led to the concept of investigating the effects of body representation on VE performance. It is possible that the representation of a "normally responding" body could provide some critical visual and proprioceptive feedback. That critical feedback may reduce confusion in performance or support better learning in terms of time or accuracy in representative simple tasks. In other words, the availability of a body representation may provide information that can be used to form a better mental model of the task environment and/or control systems functions (the VE interface). Although it was not our intention to investigate transfer or retention in this experiment, it is possible that an improved interface (with a body representation) would lead to increased transfer and/or improved retention of learned skills. The first step is to determine experimentally whether the body representation we are currently able to attain supports improved movement or task performance over "disembodied" representation. As the goal is to be able to extrapolate to training and rehearsal within complex VE systems, the experiment was performed in the context of a simple, representative task. The next major section briefly reviews the limited literature we were able to find that was germane to body representation in VE.

It must be noted that there are other factors involved in learning within a VE. Because the VE interface is a computer simulation, it can not and does not perfectly recreate all cues to

position and orientation available in normal perception. Tracking head position and generating visual displays that are drawn from large databases often lead to lags in presentation. The display devices used (typically head-mounted displays (HMD)) also result in diminished visual cues. For example, optical flow cues are generally minimal due to the narrow FOV and the level of detail (resolution) possible in the HMD systems. These deficits in presentation can lead to non-normal or contradictory cues. Lighting is often low level and projected from one generic source rather than the complicated multiple levels and sources that are common in reality and contribute to texture (which is used in distance perception). Performance decrements, transfer of training problems and even simulator sickness may result from inappropriate or artificial VE interactions. In order to provide information for the development of ICS, researchers and developers need to develop an understanding of the distortions that might be present in these VEs, ways to counteract those distortions, and methods for measuring problems. Therefore, simulator sickness measurement and effects are a part of every experiment conducted in our program, and are briefly discussed in the second section, below. In addition, presence, the feeling of being in the simulated environment, and immersion, the tendency or capability to become involved in situations, are investigated in conjunction with our research. The hypothesis is that understanding presence and immersion will provide insight to factors that can improve learning and transfer in VE simulations. A short discourse on presence and immersion is presented in the third section. This adjunct knowledge should allow us to develop strategies for minimizing the impact of VE distortions and maximizing the effectiveness of training in VEs. The general experimental task and framework are presented in the final section of the introduction.

Body Representation

There are several categories of research focusing on body representation found in the literature. Most of the research focuses on the computer and engineering development of body representation or limb function.

One aspect of body representation research is that of biomechanics for realistic animation or motion analysis (McKenna & Zeltzer, 1996). Although McKenna and Zeltzer point out that this type of representation is probably very important for multiple person training or rehearsal, their work focuses on design and development. Their point is that in dynamic simulations each participant would be better able to analyze and understand the collective tasks by clearly and correctly perceiving the actions of other participants. An example would be recognizing command gestures (e.g., squad formation commands) used in military tasks (Abel, Reece, & Smith, in preparation). Another aspect of correct representation that can provide better information for team members is clear locomotion representation (Ko and Cremer, 1996). Ko and Cremer have developed generic routines for smoothly blending different locomotion modes (walking, running, etc.) for an animated figure, reasoning that much of the activity in VEs will be movement based. These efforts address how an individual's activities are represented accurately to others.

A different aspect of body representation research is focused on how to design new interfaces based on the limits and possibilities of the human body. The main concern in this category of research is how the representation of the body works (e.g., Tolani & Badler, 1996; Singh, Pieper, Guinness, & Popa, 1996). Example issues are how well the VE-simulated user can pick up and maneuver VE objects with a VE hand controlled by a sensor-implemented hand (Douville, Levison, & Badler, 1996), or how easily can one move through a VE space using an interface device such as a joystick, treadmill, or sensor-tracked walking. The major focus in this research is on input and control concerns rather than the influence the experience has on the user.

In our literature review on body representation, we found little research on the psychological and performance issues in body representation in VE systems. This supports our contention that research is needed to investigate the obvious questions as well as discover the non-obvious issues and factors. For example, does being able to see a high fidelity 3-dimensional representation of the controlled appendage make a difference in performance? According to van Erp, Oving, and Korteling (1997), when there are sufficient 3-dimensional cues available, a spatial-mapping control (mapping the movement of the controlled object in the same three dimensions as the control device) is better than a reference-plane mapping (e.g., moving a joystick in a horizontal plane to control an object in the vertical plane). This implies that spatial-mapping control of a VE cursor would be better than reference-plane mapping, leading to the inference that the control of a VE object that represents a body part (e.g., a hand) should be mapped to the normal physical movement of that body part. These questions begin to focus on the influence of body representation as an anchor for experience and possibly an egocentric reference point for interaction.

Draper (1996; Draper, Wells, Gawron, and Furness, 1996) has done a series of experiments on the effects of a virtual body representation on the performance of object positioning and reaching tasks. In two studies, where subjects re-positioned objects in a simple or complex VE room, having a body model (arm and hand) did not influence the amount of error made in re-positioning target objects. In the third study (Draper, et al., 1996), the errors in positioning in order to reach a target (the experimental task) interacted with the degree of body representation: a visually disconnected hand representation led to more errors at low or medium heights and the full body representation created more errors at the higher height. The full body representation at this higher height (target positions apparently above the head) resulted in subjects viewing a reaching arm against a low texture background (ceiling), which may have combined to distort the subject's perceptions for reaching. The lower levels provided more texture (floor and furniture) and more of the body representation was visible, which may have added cues for the reaching task that overcame misleading cues based on the arm representation alone. In that third study, target height was a main effect, which may have been solely due to the amount of texture available at each target height. It should be noted that in all three of these studies the number of subjects used was very low (less than ten).

Slater and Usoh (1993) investigated a user's sense of presence (degree of involvement or feeling of being inside the VE, see below) in VE with and without a body representation in an

architectural walk-through. In that research, the no-body representation condition, which was slaved to the hand sensor, had only a cursor for egocentric position information. Their small pilot experiment indicated that having a body representation in VE maintained a sense of presence (see below) even when display problems were noticed, that females had a greater sense of presence with a body representation, and that the body representation increased presence for those with a predisposition to motion sickness. They also noted that loss of realism reduced presence, with or without a body representation. They did not report whether having a body representation improved or eased movement through that VE or that any learning occurred.

These experiments are extensions of typical human-computer interaction research. VE is a new way of interacting with(in) a computer environment and by its very nature attempts to be more personally vivid, immersive, engrossing, and bodily interactive. VE systems represent attempts to put the user actively in the environment rather than seated outside of it while looking in through a window. The user becomes a first person agent, rather than third person observer. The nature of the VE representation and interaction allowed by the system thus influences the mental model formed of the VE "reality" much as instruction can influence the mental model formed of a system (Park & Gittelman, 1995). Obviously, the mental model formed by a trainee will affect their performance in the learning situation, and at transfer.

Simulator Sickness

Research conducted in our program and elsewhere (Lampton, Kolasinski, Knerr, Bliss, Bailey, & Witmer, 1994; Wann, 1993) has indicated that frequently there are sickness problems found in different VE systems that may effect research outcomes. On this basis, simulator sickness is one issue that we regularly investigate in experiments within our program. We use the self-report Simulator Sickness Questionnaire (SSQ) developed by Kennedy, Lane, Berbaum and Lilienthal (1993). These researchers identified three subscales of symptoms associated with simulator sickness, in addition to a Total Severity score. The Nausea scale symptoms are general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, and burping. The Oculomotor Discomfort scale reflects problems with general discomfort, fatigue, headaches, eyestrain, difficulty focusing, difficulty concentration, and blurred vision. The Disorientation scale addresses difficulty focusing, nausea, fullness of head, blurred vision, dizziness with eyes open, dizziness with eyes closed, and vertigo. Over the course of several experiments, we have endeavored to decrease or minimize the sickness symptomology of experimental participants through control of experimental procedures.

In the earliest experiments conducted in our program, we found simulator sickness to be linked to time in the VE (Knerr, et al., 1994). Therefore in the later experiments we have limited the amount of time people spend wearing HMDs and performing experimental tasks (as recommended by McCauley and Sharkey, 1992). Over the course of repeated short-duration trials, we noted that participants seemed to develop symptoms early in the experiment rather than later, which seems to follow the pattern with sickness in simulators. Further, there is evidence that simulator sickness is lessened as experience with the simulator increases (McCauley and

Sharkey, 1992). For example, Lampton, Kraemer, Kolasinski, and Knerr (1995) studied simulator sickness in a tank driver trainer under non-experimental conditions (non-interference in the training program, without selection of students or manipulation of training conditions). The tank trainer has a visual display and a six-degree of freedom motion platform, and it is used for initial driver training. They measured SSQ scales before and after training sessions using the tank driver trainer. The analyses reported significant post-exposure SSQ score differences for the Total, Nausea, and Disorientation scales between the first two sessions on the trainer and the mid-course or the last session scores. The observed decrease in the SSQ scores over the course of training experiences indicates that the students were adapting to the tank driver trainer (Lampton, et al., 1995).

A review by Kolasinski (1995) identified individual, equipment, and task variables that can influence the incidence of simulator sickness. Kolasinski's (1995) review on simulator sickness concluded that simulator sickness research results provide a good basis for hypotheses about sickness that occurs in VE, and that the practicalities of VE research mean that research on simulator sickness in VE will be ancillary. Kolasinski (1995) has identified many factors associated with simulator sickness, and classified them into three major categories. Factors can be individual, task, or equipment (simulator) based. As McCauley and Sharkey (1992) point out, much of the research on simulator sickness has been conducted on a self-selected and screened sample of the normal human population – pilots. Pilots in the armed services are motivated and have been trained to adapt to extreme motion, with the less adaptive being washed out. The normal population of VE users will presumably eventually go through the same selection process, although it will probably be a less restrictive process. In the interim, individual factors such as age, gender, mental abilities, and other personal characteristics need to be investigated (Kolasinski, 1995). General task characteristics such as degree of control, duration of experience, global visual flow, head movements, etc. (Kolasinski, 1995), can also affect simulator sickness severity. This task characterization emphasizes the need for investigation of simulator sickness across many task domains. Perhaps the most important category of simulator sickness factors in are the VE equipment characteristics, such as position-tracking error, visual display characteristics, scene content, etc. (Kolasinski, 1995).

It was not the intent of this research to directly manipulate equipment or task variables in an attempt to identify their contribution to VE sickness. The major factor of interest was the effect of body representation on movement performance, and we did not anticipate differences in simulator sickness to be based on that factor. However, the administration of multiple short trials provided the opportunity to administer the SSQ several times during the experiment, which would allow us to track and document some of the assumptions we had begun to form while conducting other research. Studying the course of symptom development and recovery offered the opportunity for demonstrating adaptation to a VE in terms of induced sickness, even without being able to manipulate any of the identified major parameters (Kolasinski, 1995). Based on observations made in prior studies at our lab, we hypothesized that there would be a significant increase in symptomology over the course of the trials and that the symptoms would reduce to near normal after a recovery period.

Presence and Immersive Tendencies

The efficacy of VEs has often been linked to the sense of presence reported by users of those VEs. Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another (Witmer & Singer, 1994, 1998). While the concept of presence has been widely discussed, only a few researchers other than Witmer and Singer (1994, 1998) have attempted to measure presence and relate it to possible contributing factors. Barfield and Hendrix (1995) have used simple direct questions as measures of presence to show that update rate affects presence. Update rate is the frequency (in frames per second) at which computer-generated images change in response to user actions or to other dynamic aspects of the simulation. Prothero and Hoffman (1995) have shown that limiting the FOV near the eye using an eye mask reduces the amount of presence reported, again using a direct query about the subjective experience of presence.

While results relating measures of presence in VE to learning and performance in the VE and in the real world have been mixed (Witmer & Singer, 1994; Bailey & Witmer, 1994), many of the factors that appear to affect presence are known to enhance learning and performance (Witmer & Singer, 1998). Some situational factors that are believed to increase immersion, such as minimizing outside distractions and increasing active participation through perceived control over events in the environment, may also enhance learning and performance. Other factors may be more internal, such as tendencies toward involvement and selective attention, or familiarity with the task and situation. These tendencies are independent of the situation (Witmer & Singer, 1998), and we measure them with the Immersive Tendencies Questionnaire (ITQ). Because many of the factors involved in learning and performance logically should increase presence, it would be counter-intuitive if positive relationships between presence and performance or between presence and equipment configurations that increase active participation were not found. The ITQ and Presence Questionnaire (PQ) are administered before and after (respectively) all of the experiments conducted in the SSRU program. The results from the questionnaires will be examined for relationship with the experimental variables, the VE equipment configuration, and the SSQ results. One expectation is that scores on the PQ will increase with any VE configuration that increases the normal interactive stimuli. For example, walking (in place) and turning the torso to control movement should be more immersive than manipulating a joystick. In this experiment, having a relatively normal body representation for position and orientation feedback should produce higher PQ scores than an abstract representation related only to hand position.

Body Model Experiment

This experiment investigated the influence of a virtual body representation on movement performance during a search task in VE. The hypothesis was that the presence of a virtual body would result in learning better VE movement skills by providing visual feedback on body location and orientation. Movement performance in VE is basic, and will occur in training or mission rehearsal within the context of other tasks. Therefore, a prototypical search task was

used as the setting or contextual frame for movement through the environment. Several sets of rooms with balanced complexity were developed in which participants could search for a simple target, a briefcase. While the briefcase is not a military target, it is distinctive and small enough to be placed in partially visually obscured locations. In order to provide normal feedback about body position and orientation, the Body Model participants experienced the VE with a body representation linked to their point of view, with representations of correctly tracked and positioned shoulders, feet, arm (right only), and hand. The Pointer group experienced the same VE and performed the same task using the same sensor monitors, but with only a visual wand pointer representing their right hand position. The Pointer condition therefore would not provide feedback about body position other than the hand, although the view would provide correctly positioned and tracked visual orientation information. Movement measurements included time to move and number of collisions during search, target acquisition, and maneuvering to exit phases in the target rooms. The total time to search and exit, and total number of collisions was collected in non-target rooms, as there could be no clear separation between search, acquisition, and exit phases when there was no target present.

In addition, as discussed above, changes in simulator sickness symptoms over the course of the experiment were measured. The hypothesis was that symptoms would increase during the VE experience, and then decrease during a recovery period after exposure. The SSQ was administered prior to exposure to the VE system, during a break in the middle of the experiment, immediately after the experiment concluded, and at the end of a thirty minute recovery period. Each of these administrations was given on a CRT while participants were seated. As a normal adjunct to experiments conducted in our program we administer the following questionnaires; biographical information using a standard questionnaire, immersive tendencies was measured by the ITQ before exposure to the VE, and presence was measured by an administration of the PQ at the end of the experimental session. These questionnaires were also administered in this experiment. All of the questionnaire data was investigated for relationships within this experiment, and compiled for further analysis across program experiments.

Method

Subjects

Experiment participants were recruited from the University of Central Florida and Valencia Community College. Thirty-two participants, 14 females and 18 males, completed the experiment (10 withdrew based on their perception of excessive simulator sickness symptoms). All participants, including those that withdrew, were given class extra credit or monetary compensation (five dollars per hour) for their time. Except as noted below, information about the experiment and participants is based on those who completed the experiment. Participants ranged in age from 18 to 44 with a mean age of 22.5. The participants averaged eight hours a week of computer use. Eleven participants reported a history of motion sickness, but only four rated their susceptibility as more than mild. Only four participants had any previous experience with VEs, and only two of these had experienced more than two interactions. Ten subjects

withdrew from the experiment because of simulator sickness, six females and four males, three from the Body Model condition and seven from the Pointer condition. They ranged in age from 19 to 26 and on average completed two trials before withdrawing from the experiment. All subjects that withdrew were kept onsite until symptoms had diminished to acceptable levels.

Materials

VE Equipment. This experiment was performed at the University of Central Florida (UCF), Institute for Simulation and Training (IST), with ARI equipment that is maintained and operated by the Visual Systems Laboratory (VSL). The visual display information was generated using Performer^{tm} and adjunct special software developed by the IST VSL. The experimental environment was generated and data were captured using a Silicon Graphics ONYX^{tm}. The visuals were presented through a Virtual Research Corporation VR4^{tm} HMD. The VR4 has 48^0 Horizontal by 36^0 Vertical FOV, with 742 x 230 color elements in each lens. Following the method used by Warren & Rolland (1991) this results in a color-triad resolution of approximately 428.4 x 132.8 (keeping the same aspect ratio of 3.226 to 1). Head, shoulder, feet, right arm, and right hand motions were registered by six Ascension Flock of Birds^{tm} sensors and tracked by an Ascension Flock-of-Birds^{tm} magnetic tracker. The head tracker was mounted on the HMD, the shoulder tracker was on a wooden back-pack frame that positioned the sensor between the shoulder blades, the foot sensors were strapped at the ankles, the arm tracker was strapped above the elbow, and an in-house manufactured hand-held interactive input device was held in the hand as the positioning/acquisition tool for the virtual wand. A sensor was attached to the bottom of the device for tracking purposes while a button embedded in the hand control, when pushed, activated the acquisition function of the virtual wand (made the target disappear).

Virtual Environment. Twenty-four different room configurations were developed for the study and rated (by SSRU researchers) for complexity as high, medium, medium-low, or low. The twelve rooms rated medium and low (six each) were developed as VE rooms. The VE rooms consisted of typical office spaces (see Figure 1), including: office cubicles, file cabinets, small meeting areas, conference rooms, etc. From these rooms, eight different sequences were created, each consisting of six rooms in sequence (referred to as one trial sequence). Each trial sequence counterbalanced low and medium room configurations. A counterbalanced trial order was used to balance the order of presentation across participants and minimize repetition of target placement for each participant. Three targets were used within each six room trial set, so that targets were in half of the rooms that the participant searched on any given trial sequence. All targets (briefcases) were placed next to furniture on the virtual floor in an upright position (no target was placed under a desk, on top of cabinets, or between furniture and a wall). A representation of the IST reception area was constructed and attached to all room sequences for use as a training room (see the bottom room in Figure 1), and as a neutral room for starting the experimental trials. A similar representation was used as the last room in the sequence, which the participant was required to enter to finish the trial sequence. The virtual Body Model used in this condition is shown in Figure 2.

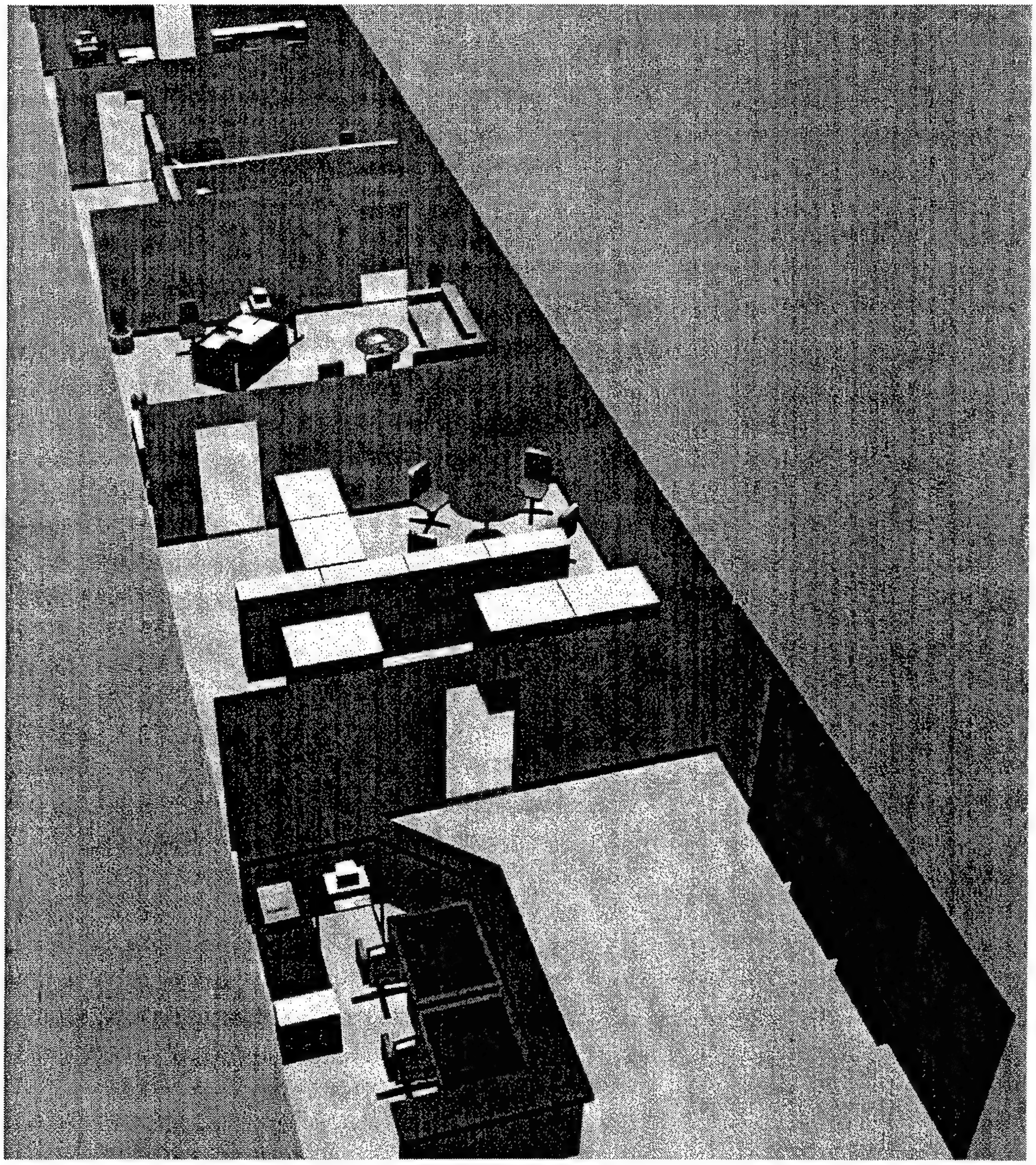

Figure 1. Example of experimental room series.

Training Materials. A videotape of the experiment apparatus, the "suiting up" procedure, and the VE training room was made to help participants learn how to put on the equipment, move, and acquire targets in the VE experiment. The demonstration of movement skills showed how someone wearing the sensors should move forward, turn while walking, turn while standing in place, and move backward. The demonstration of target acquisition included how to manipulate the VE pointing device (i.e. a virtual wand) and how to acquire targets. An

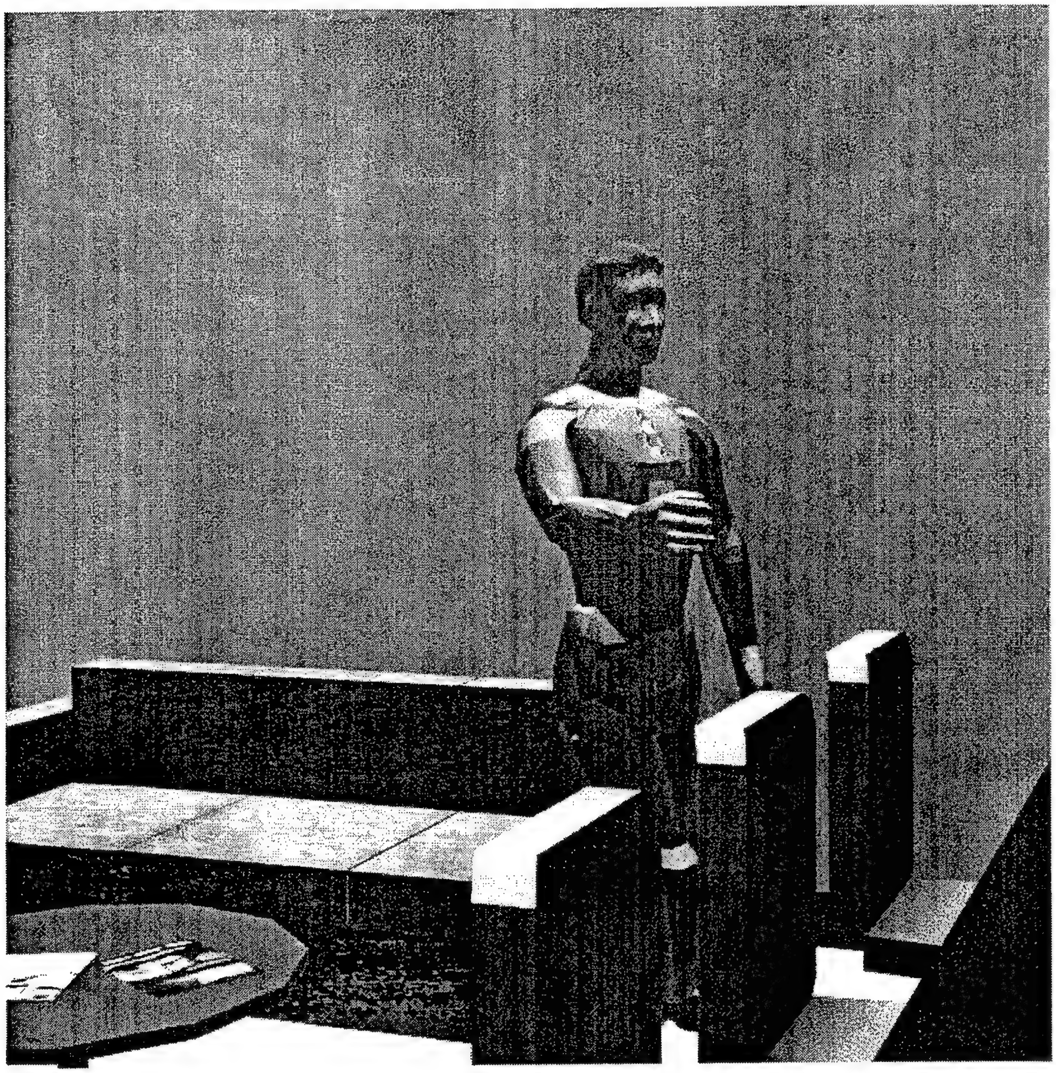

Figure 2. Body representation used in experiment.

experimenter was present to provide answers if questions were asked during the viewing of the training video.

Questionnaires. A research participant information questionnaire was administered (see Appendix A) to gather self-report biographical information on vision, motion sickness susceptibility, health, fitness, amount of sleep, current medication use, and experience with computers or VE. The SSQ (Kennedy, Lane, et al., 1993) was used to assess changes in symptomology over the course of the experiment and during a recovery period after the experiment, as noted above. The ITQ (Witmer & Singer, 1994, 1998) was used to investigate participant tendencies toward involvement and immersion in different kinds of concentrative experiences. The PQ (Witmer & Singer, 1994; 1998) was used to assess participant's subjective experience while performing different tasks in VEs.

Procedure

The experimental design was a single factor, repeated measures design. The body representation factor had two levels: Body Model or Pointer. The conditions were randomly assigned, with the constraint of assigning equal numbers of each gender to each condition. Each participant's eye height was measured and entered into the computer to adjust the viewing angle in the VE, as well as the virtual wand and the Body Model size. The length of the pointer was adjusted by participant height in order to hold the reaching capability constant across participants. In the Body Model condition, the participant was provided with a self-referenced VE body representation (based on the sensor ensemble). The participant could view the front of the body by shifting their gaze towards the floor. The participant could also view the virtual wand, represented by a solid ball and light bar held in a modeled hand with an arm connecting to the (referenced) right shoulder. The Pointer condition provided the participant with only the wand representation for visual reference.

Movement of the virtual wand (in both conditions) was accomplished by moving the right arm in the upper mid-line area of the body[1]. The collision detection routines were the same in both conditions, and used two intersecting detection vectors, one the width of the body and one extending front to back of the body position. The width of the body was set at 17.25 inches (the average for males and females combined, Mil-STD-1472D, 1988), which was not varied as the body size changed with eye-height. The front projection vector was used to predict collisions during the next step, and to provide feedback on the collision. The width vector was used to detect side or glancing collisions with walls and furniture.

The experiment consisted of three phases. The first phase was introduction, questionnaires, and briefing; the second phase was the VE experiment; the third phase was the post-experiment questionnaires and waiting period. In the first phase, participants viewed a taped briefing that contained information about the nature and conduct of the experiment, demonstrated walking, and showed target acquisition in the VE. After consenting to participate, participants completed a biographical data form. The answers provided by the participants on the research participant information questionnaire was the first step in determining whether they could participate in the experiment. Minimum acceptance criteria included 20/20 vision (natural or corrected), low susceptibility to motion sickness, and a low level of experience with virtual reality simulations. All participants that met these criteria then filled out an SSQ (Kennedy, Lane, et al., 1993), the second participation qualifying questionnaire. If participants had high symptoms on the SSQ, they were queried about their symptoms and participants that were ill were dismissed. An ITQ (Witmer & Singer, 1994; 1998) was then administered before the experiment began.

In the second phase of the experiment, participants donned the VE equipment and started in the VE practice room, an initial training room used for all the experimental sequences. On the

[1] The red beam of the wand was always visible. When moving the virtual wand the user would normally only see the beam, the user would have to move their hand forward and away from their body to be able to see the virtual ball.

first trial, subjects were guided through a locomotion and acquisition practice session in the entry room (see below). The experiment began when the participant had successfully completed the practice session. After completing a trial, a five-minute break with HMD removed was taken. After completing three trials, the participant removed all VE equipment and took a ten to fifteen minute rest break. During this break, the participant completed another SSQ (Kennedy, et al., 1993). The experimenter questioned the participant to see how they felt. If the SSQ and/or participant indicated that extra break time was needed, the participant was given an additional ten to fifteen minutes out of the VE. If that break did not prove to be sufficient, the experiment was terminated and the end-of-experiment routine was started. If the participant could continue, the VE equipment was donned again and the last three trials of the experiment were administered in the same manner as the first three trials.

VE familiarization training was conducted for both experimental conditions using the practice room that started each trial. At the beginning of the first trial participants were required to follow a series of scripted instructions in the practice (entrance) room, while the experimenter monitored and provided scripted feedback. The purpose of these instructions was to teach the participant how to move, turn while walking or standing in place, manipulate the virtual wand, and acquire a target. Acquisition required the light beam projection from the hand control to intersect the target (the color of the beam would change to indicate intersection). At the end of the training, the participant was asked whether they felt comfortable with the locomotion and acquisition tasks. If the answer was affirmative, they would begin the experimental trial. If not, they were given additional time in the practice room. In the first experimental room, participants were also given feedback on their performance, with emphasis on *speeded search* and *rapid acquisition* of the targets. During the experiment, if a subject re-entered to a room previously searched, the experimenter advised the subject that they had already searched that room.

The third phase of the experiment started with the final removal of the VE equipment, at the end of the experimental trials. The participant was given another SSQ (Kennedy, et al., 1993) as well as a PQ (Witmer & Singer, 1994; 1998). The participant then listened to a taped debrief and received either experimental credit or payment, at their discretion. The post-VE phase took approximately thirty minutes during which participants were watched for signs of simulator sickness and asked about symptoms indicating simulator sickness. To help ensure that the participant was not experiencing any deleterious simulator effects, they completed one more SSQ before leaving. The experimenter checked the symptoms for acceptable range before releasing the participant. None of the subjects that completed the experiment experienced sufficient distress that more time was required for recovery. The few subjects that could not complete the experiment were retained until their self-reported symptoms were reduced to the point that they felt quite capable of continuing their normal activities.

Results

Task Performance

Target Acquisition. The number of targets acquired was analyzed using ANOVA, with no difference found between body-representation conditions, nor improvement over trials. The targets were located approximately 88% of the time (ranging from 81% to 94% in different trials and conditions).

Movement during Search. The primary data of interest was time to search and collisions experienced during search in rooms with targets. Both the time and collision data were analyzed as totals for each trial; and also split into three separate measures for the target rooms within each trial. The first derived measure was the visual acquisition interval, which covered the time from entering the room to the time when the target entered the visual frame of the HMD, and is referred to as Time to Visual Acquisition. The assumption for the visual acquisition interval is that when the target entered the visual frame without visual obstruction it would be seen. The second derived measure was the physical acquisition interval, which covered the time from the target entering the visual frame in the HMD to the acquisition of the target via the wand. This is referred to as the Time to Physical Acquisition. The final derived measure was the exit interval, covering the time from physical acquisition to leaving the room. It is referred to as the Time to Exit. The number of collisions during these intervals was also derived. Total time and collisions were also analyzed for the non-target rooms, but obviously could not be separated into segments. As the experimental design employed repeated trials, the performance changes over trials were analyzed as a part of the ANOVAs for all these measures.

There was no significant overall difference in the search time measures or number of collisions, for either target or non-target rooms, between the body representation conditions. Participants did improve over trials, as shown by the significant changes over trials for all time measures except the Time to Visual Acquisition: Total Time in Target Rooms ($F=16.08$, $p<.001$, see Figure 3), Time to Physical Acquisition ($F=20.9$, $p<.001$), and the Time to Exit ($F=8.04$, $p<.001$). An example of the general improvement in the time means is presented in Figure 3. There were also significant changes over trials for two collision measures: Total Collisions in Target Rooms ($F=3.93$, $p=.002$) and Collisions during Physical Acquisition ($F=5.48$, $p<.001$) both decreased. An example of the changes in the mean collisions presented in Figure 4. As can be seen in Figures 3 & 4, the Pointer means and collisions are almost always higher than the Body means, although the differences are not significant.

Simulator Sickness

The SSQ (Kennedy, et al., 1993) was used to assess simulator sickness (see above for schedule of administration). Each of the symptom scores (see above) are summed and weighted

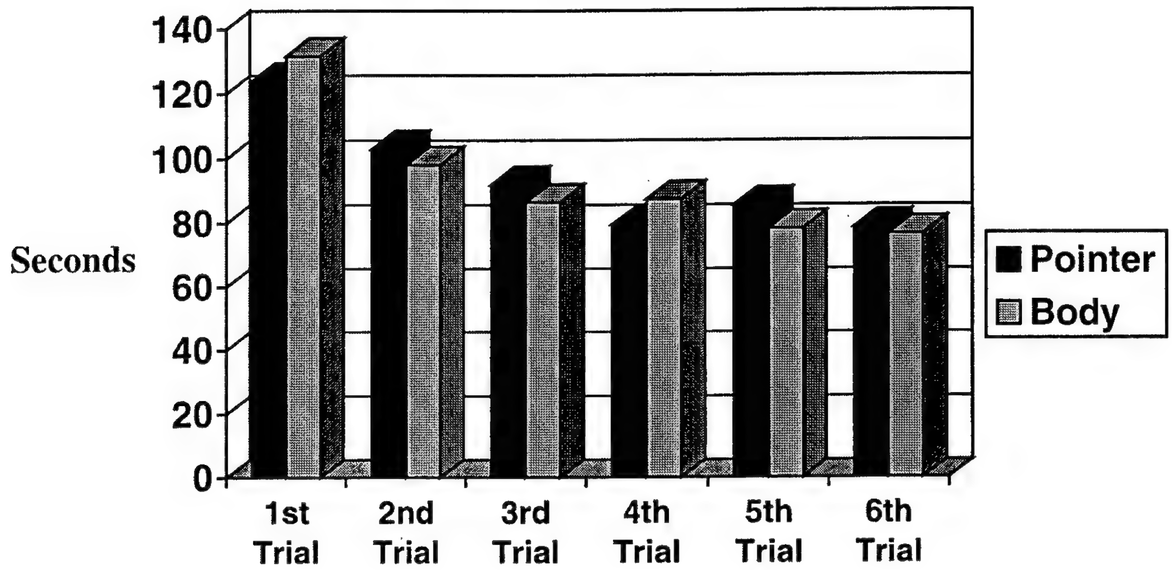

Figure 3. Mean total time in target rooms (n=16/group).

to derive the subscale scores. The subscale sums are also added and the total score is weighted to form a Total Severity measure. The SSQ scores and the changes in all scores over the course of the experiment were compared based on body representation condition, with no significant differences. However, over the course of the experiment, there were many significant differences found between the subscales using planned comparison t-tests. These analyses revealed that simulator sickness increased significantly from pre-VE exposure to the middle of the experiment, was still significantly elevated at the end of the experiment (relative to the pre-experiment measure), and was <u>not</u> significantly different from the initial scores by the end of a thirty minute recovery period (see Table 1 and Figure 5).

Table 1.

Planned Comparison of Pre-Experiment SSQ Scales and those Administered during the Experiment

Pre-SSQ to:	Total Score	Nausea Scale	Oc-Motor Scale	Disorient. Scale
Mid-SSQ	t=-5.06, p<.001	t=-4.15, p<.001	t=-4.91, p<.001	t=-4.92, p<.001
Post-SSQ	t=-4.56, p<.001	t=-3.43, p=.002	t=-4.05, p<.001	t=-5.02, p<.001
Final-SSQ*	t=-1.85, p=.155	t= -1.91, p=.243	t=-1.18, p=.248	t=-2.00, p=.054

(N=32, df for each test = 31, *df=30).

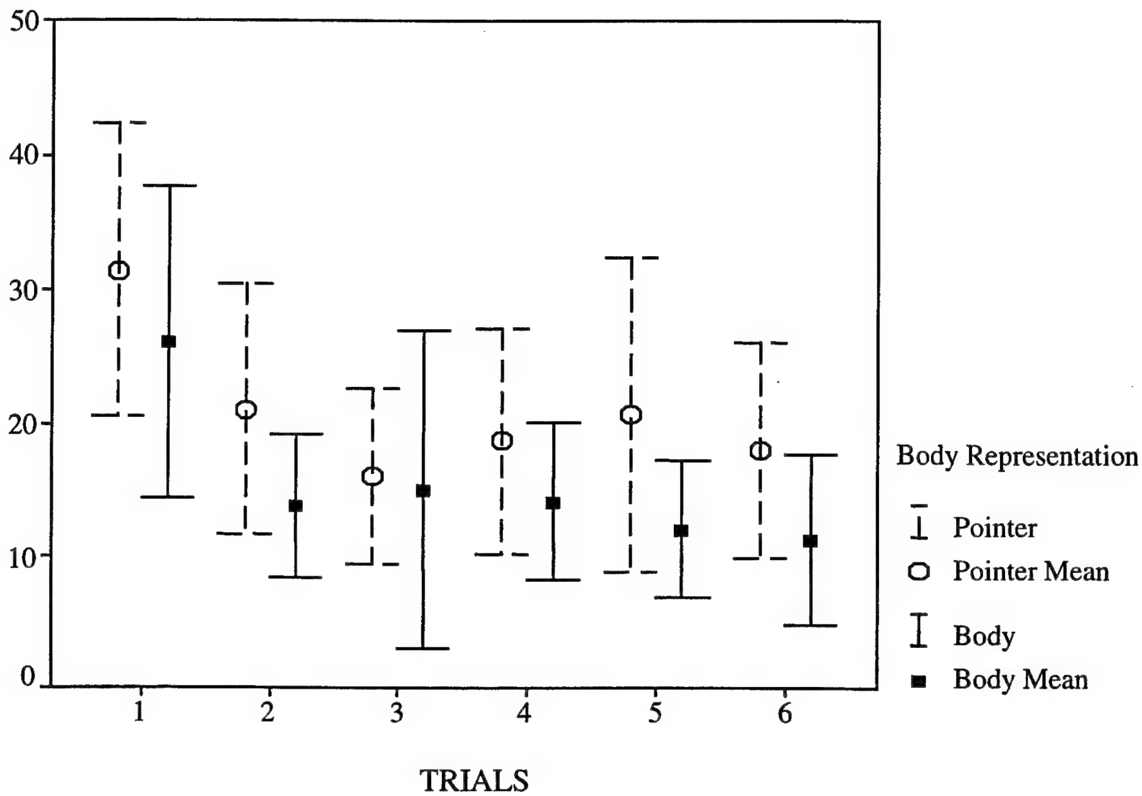

Figure 4. Collision means & 95% confidence intervals by body representation condition and over trials. (n=16/group)

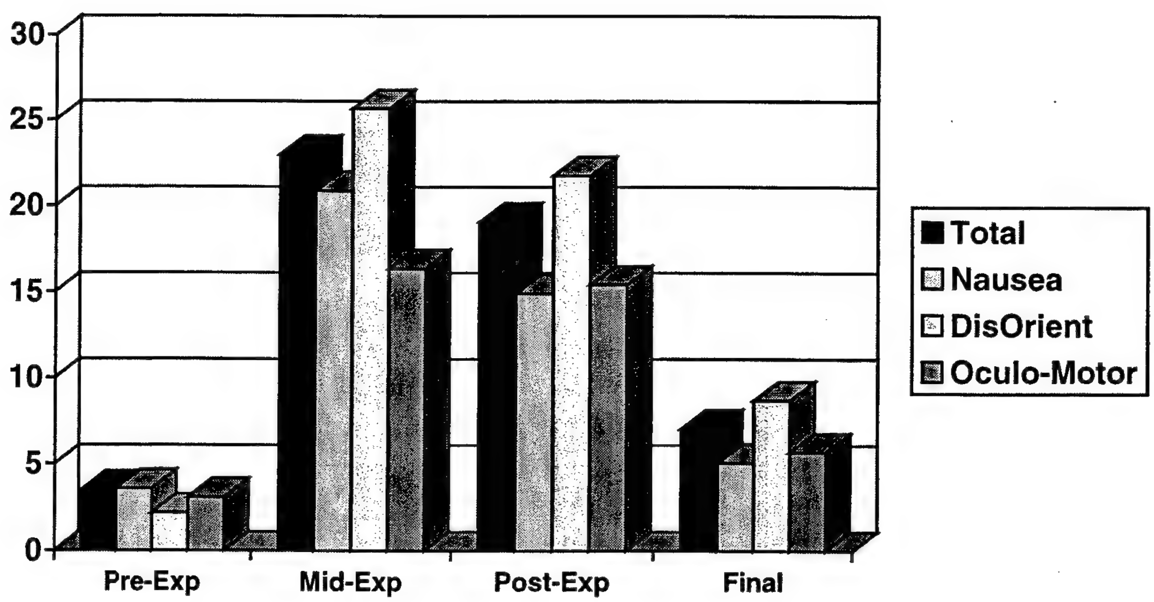

Figure 5. Mean SSQ total and subscales for experiment administrations.

There were also significant differences between the Mid-Experiment measures and the Final SSQ administration, but no significant differences were found between the Mid-Experiment and Post-Experiment administrations (see Table 2). In addition, there were significant differences between the Post-Experiment and the Final SSQ measures (after the thirty-minute recovery period, see Figure 5 and Table 2).

Table 2.

Planned Comparison of SSQ Scales Administered during and after the Experiment

Mid-SSQ to:	Total Score	Nausea Scale	Oc-Motor Scale	Disorient Scale
Post-SSQ*	t= 1.31, p=.198	t= 1.90, p=.067	t= .37, p=.712	t= 1.25, p=.222
Final-SSQ	t= -4.78, p<.001	t= -4.68, p<.001	t= -4.01, p<.001	t= -3.91, p<.001
Post to Final	t=-3.93, p<.001	t= -3.75, p=.001	t =-3.61, p=.001	t= -3.14, p=.004

(N=32, df for tests=30, *df=31).

<u>Presence</u>

The ITQ and PQ were used to assess possible immersive effects on the experiment, and effects of the experimental manipulation on presence. This required analyzing the ITQ Total and subscales (see Witmer & Singer, 1998, for details) for differences between assigned experimental group, with no significant differences being found. The Presence Questionnaire scales were also analyzed based on the body representation factor, with no significant differences found.

Discussion

<u>Movement Performance</u>

The experiment did not find significant differences in movement or search performance as a result of body representation. Movement through the environment was not trivial but could be adapted to, as shown by the significant improvement over trials (approximately a fifty-second improvement, see Figure 3, above) and fewer collisions per trial (see Figure 4, above). Finding the same pattern in both the speed and accuracy measurements for both of the body representation conditions seems to indicate that self-representation (having a set of body referenced visual cues) does not aid in the adaptation to movement through the VE.

Obviously, the framing context for this outcome is the VE configuration that was used in the experiment, the strategies adopted by the participants, and the activities required in the experimental task. One possible activity-based explanation for the findings is that movement *after* target acquisition is different from movement *during* target search. As presented in the discussion, the focus of the experimental manipulation was movement in the VE, and we decided

to investigate movement in the context of a generic task rather than looking at pure movement skill. Moving toward a target after visual acquisition has been made, or moving to exit the room after physical acquisition of an object has been made, is done with a constant goal. There is only one act involved, and therefore adaptation to a new environment and interface (the VE) may be easier or occur earlier. After visual acquisition, the place-to-move-toward is fixed and gaze can be shifted in order to make efficient progress (fewer collisions) toward the objective. As this goal directed movement skill is developed, less time is taken to move and fewer collisions occur during movement. Our VE interface was set up to allow direct locomotion control (by walking in place), which seemed to provide reasonably good kinesthetic cues, especially corresponding to movement direction. This may have supported the significant improvement found during the more single-activity, movement-oriented segments of the task (physical acquisition and exiting target rooms). Support for this argument can be drawn from the contrasting lack of improvement during the visual search segment of the task.

At least two strategies for the search activity were discerned through observations of the subjects. One apparent strategy was to move, halt, and visually search the available environment while stationary, then move again to a new location for continued search. The visual search may have been so difficult that no improvement was possible with the amount of practice allowed, although target positions were selected for moderately difficult visual acquisition which would allow improvement. The time required by this search strategy would seem to be minimally affected by a body representation, and the lack of differences in collisions might reflect a higher priority given to target detection over movement path predictions which could decrease collisions. In addition, the size of the FOV ($48^{\circ} \times 36^{\circ}$) also seemed to require extensive scanning, and if stopping in order to scan was the major search strategy, that would not tend to show improvement over trials. The second strategy was to visually search while moving. This strategy also seemed to place target detection and total environment search coverage ahead of rapid movement or predicting where collisions might occur during movement. One complication to this strategy is that the head-movement required by the restricted FOV during visual search and movement can often lead to small changes in movement heading (which was based on shoulder direction) during movement, which might increase the likelihood of collisions (again with no difference between conditions). Collisions naturally increase the time spent in performing the search while moving strategy, because time is spent in the collision state and recovering from the collisions.

With either strategy, the restricted FOV may have differentially contributed to the difficulty of the search phase of the task. The importance of the size of visual field has been demonstrated in research on performance of guiding-movement tasks. For example, Wood and Troutbeck (1991) investigated the effect of FOV on driving performance. They found that restricting the visual field from "normal" (approximately 120 degrees for the binocular field, Kaufman & Christiansen, 1984) to forty degrees, and even further to twenty degrees, decreased peripheral awareness, impaired obstacle avoidance, and increased maneuvering errors during a driving test. The time to complete the test-driving course was also significantly increased, primarily through the adoption of a slow-down strategy (in spite of instructions to the contrary)

when performing with reduced FOV. Impaired obstacle avoidance during driving is comparable to collisions during the search phase in this experiment, as obstacles have to be detected and perceived as collision objects before they can be avoided. It seems reasonable that changes in the FOV would change the performance aspect of the search task. Following this logic, it seems reasonable to predict that increasing the FOV would ease any visual search activity, decreasing the time required for visual search and therefore decreasing the overall time required for any "search and acquire" task.

Another possibility deserves mention. Controlling movement while searching in the Body Model condition may have increased the cognitive load by forcing compensation for minimal offsets in the body representation during movement and searching for the target. Adjusting to a different "body image" and using that body image to predict collisions could require extra processing or introduce errors when the body image did not match the participant's actual body parameters. The hypothesized disruption may have hindered the expected overall positive effects of having a body representation. There were no other differences in the overall VE configuration that could have affected the outcome, as the Pointer group used the same sensor array and computer routines for movement, vision, and wand control. This may mean that the body representation was in some way actually intrusive. This would be in spite of the considerable effort expended in making the body representation adequately (although generically) sized, shaped, colored, textured, and closely coupled to movement of the sensors worn by the subjects. Support for the increased cognitive load hypothesis comes from the lack of improvement over trials during the search phase of the task (although the physical acquisition and exit movement phases did improve significantly).

Three changes can be made to follow-on research investigating the effect of body representation on adaptation to movement and task performance in a VE. First, some method of investigating HMDs that are larger than currently available must be developed. Then a similar search task could be used to investigate the effect of different FOV on body representation during a search task. It may be that having a deeper FOV (a larger vertical array), would provide more normal visual input from lower in the visual field, enabling the acquisition and use of body orientation and location cues relative to the environment. Merely increasing the vertical aspect without a horizontal widening would probably not improve search task performance as no extra information about the peripheral or surrounding environment would be available. The search task would probably benefit from increasing the horizontal FOV, as that would increase the area available for rapid visual search while decreasing head movement required to search the same area. This FOV concept yields three hypotheses. First, that increasing only the vertical FOV will improve movement speed and decrease collisions during a simple search task without actually improving the search task speed or accuracy. Second, that increasing only the horizontal FOV will improve the speed, and perhaps the accuracy, of the simple search task without improving overall movement speed or decreasing collisions. Third, that increasing *both* horizontal and vertical FOV will improve all aspects of the simple search task and movement during the task.

The second change that could be made in follow-on research is to use a different type of task. If a pure movement task were used, especially one that required a relatively fixed downward gaze during movement, then the body representation would be emphasized without the (presumed) complication of a primary search task. The hypothesis is that a pure movement task would be easier to adapt to with an easily referenced body representation (as a result of the required downward view), leading to more rapid improvement in movement control over trials. It is not clear whether increasing the FOV in the pure movement task (which would normally encourage looking downward) would contribute to any effect of body representation. It is probable that an increased vertical FOV would make it easier to see the body representation even within a task that encouraged looking down behavior. An increased horizontal FOV would probably not have an effect on a pure movement task, as little or no extra information would be gained from the wider FOV.

Finally, the third alternative in a future investigation of the effect of body representation on performance may be entirely training based. Training people to move in VE systems might be enhanced if a visual representation was central to the training. The visual body representation cues, in conjunction with movement training might improve adaptation to the VE, in terms of learning to rapidly and efficiently move within a VE. The hypothesis is that movement speed and accuracy would be enhanced by training in positional cue recognition, and further improved with the additional cues provided by full body representation. That training in pure movement could then transfer to movement during many other movement-based tasks learned in the VE.

Simulator Sickness

The scores and changes in scores over the course of the experiment were not expected to change based solely on body representation, and did not. There were significant increases in symptomology expected over the course of the experiment, and these expectations were fulfilled. The course of the experiment found simulator sickness as measured by the SSQ; 1) increasing significantly from pre-VE exposure to the middle of the experiment, 2) still being significantly elevated at the end of the experiment, and 3) not being significantly different from the initial scores by the end of the recovery period. The significant increase in symptomology during the initial phase of the experiment (the first three trials) follows the normal pattern of VE experience that we have found in previous research.

An interesting pattern is the (non-significant) decrease between the mid-experiment administration and the end of experiment administration. If sickness was driven solely by time of exposure and there was no adaptation, participants would become increasingly symptomatic over the course of the experiment. The expected pattern would be a continuing increase in SSQ scores, although they might not be increasing significantly. The non-significant decrease might mean that people were adapting to the sensory differences (from reality) during the course of the experiment. One caveat to this interpretation might be that it was only those people who could adapt that stayed in the experiment. However, of the simulator sick subjects who resigned (N=10), most (8) did not finish the first three trials and several did not finish the first trial. This

seems to indicate a rapidly developing, high level of sickness from the outset of the experience for the dropout subjects. The second caveat is that participants spent less time in the last three trials (an average of 489 seconds for all three trials) than they did during the first three trials (an average of 647.6 seconds). The shorter overall time in the VE might account for the lower scores on the SSQ, although the short mid-experiment break did not provide sufficient time for complete recovery (to pre-experiment levels) from the first three trials.

The significant decrease from post-experiment to the final administration of the SSQ is encouraging. This is evidence of a reasonable recovery from symptomology shortly after cessation of the VE experience. Previous subjective observations during our research efforts indicated that this might be the case, but it had not been documented or tested. The implications for future research, VE based training, and other applications requiring more extended periods of exposure or repeated exposures is clear. A large proportion of the populace (approximately seventy-six percent based on our dropout rate) seems to adapt to VE successfully, and therefore VE simulator sickness may be less of a problem, especially as technology improves.

The rapid onset of symptoms may have been due to the full immersion introduction that we used. We have observed lower dropout rates in other experiments in our program that had less complicated and immersive VE configurations. It is possible that phasing the immersive aspects of the VE configuration would ease the adaptation to the VE, and decrease the dropout rate. An alternative or additional approach may be to train subjects in techniques that would decrease activities in the VE that seem to increase symptomology, such as excessive head turning at high rates of rotation. This would require experiments more directly addressing explicit VE activities, like head-turning, that might influence simulator sickness symptoms.

It should be clear that since the experiment was conducted under normal ethical rules for the use of human subjects, some information about the incidence of simulator sickness symptoms was provided to the participants and they were allowed to withdraw at any time for any reason. While it is possible that some of the dropouts were unduly influenced by our emphasis on their right to withdraw if they felt ill, it seems unlikely that this alone would account for all of the withdrawing participants. These data, including the data from dropout subjects, will be analyzed in conjunction with simulator sickness data from other experiments. Those analyses should provide a better understanding of the simulator sickness symptomology patterns resulting from VE experiences.

Presence & Immersive Tendencies

Like the simulator sickness assessments, presence and immersion have been an ongoing but ancillary research issue in our research program. Previous work (e.g., Singer, et al., 1995) had found increases in PQ scores resulting from a more interactive VE configuration. In this experiment, finding that the PQ scores did not change significantly as a result of the addition of a body representation indicates that the body representation we used was not immersive. The slight abnormalities in the body representation hindered the perception of presence, and may

have diminished the hypothesized possible overall positive learning and immersive effects of having a body representation. There were no other differences in the overall VE configuration that can explain the PQ results, as the Pointer condition used the same sensor array and computer routines for movement, vision, and wand control. As noted earlier, the overt acceptance of the body representation was good, based on informal comments made by participants and during demonstrations of the system. One possible explanation for this finding is that the body representation may have increased expectations of the control and feedback that would be available, leading to lower scores on the questionnaire control issue items when the expectations weren't completely fulfilled. The data collected during this research will be analyzed in conjunction with data collected in other research in order to shed light on the immersive factors resulting from different VE configurations, tasks, and activities.

Conclusion

Body Representation. The results of this and the few other experiments (e. g., Draper, et al., 1996) on body representation seem to indicate that body representation is not as important a factor as might have been expected. A straightforward interpretation of these results seems to indicate that there is no need for body representation. However, it is possible that simple body location feedback interacts with a mix of HMD characteristics, task parameters, and training in movement techniques. One experiment cannot adequately explore the complex interactions of short range cueing and guiding information that can be acquired from different sources, using different strategies or techniques, and then used for the many activities that combine into seemingly simple tasks.

Simulator Sickness. Important information from this experiment comes from the pattern of SSQ results over the course of the VE experience. Our results indicate that those people that do adapt to the VE will probably be able to readapt relatively rapidly to the normal environment, or return to their prior normal state as measured by the SSQ. The readaptation can be expected to occur within approximately thirty minutes after exit of the immersive situation, when the VE experience totals less than approximately thirty minutes (in short exposures and with breaks). These results provide the basis for adding to preliminary safety recommendations about VE use for training and entertainment. At least one recommendation has been made (Stanney & Kennedy, 1997) that expected recovery time should be approximately equivalent to exposure time. Our results provide some support for that contention, in that people were averaging approximately nineteen minutes performing the experimental task, with perhaps another nine or ten minutes in the VE while not doing the experimental task, and readapting in thirty minutes or less. (Note that there were breaks during the experimental sequences that may also have alleviated the sickness phenomenon and that this data does not include the subjects that removed themselves from the experiment.) It must be noted that we still do not know what the recovery time might be for someone accumulating more than thirty minutes of VE exposure, or accumulating thirty minutes or more in a single session without breaks. Obviously, the results of one experiment cannot be used as the basis for comprehensive guidance over a wide range of conditions and tasks, but our results confirm and extend previous guidance.

An additional suggested safety recommendation about VE use in training and entertainment can be inferred from the results of this research. Given the apparent rapid onset of simulator sickness symptomology in our relatively complex VE, we infer that the initial experiences in VE should be less complex, and perhaps designed to provide individuals with the opportunity to more easily adapt to the VE system and task requirements. While our results seem to indicate that a large proportion of people can rapidly adapt to the VE situation, and then rapidly recover from their experience, approximately one quarter of our participants experienced rapid onset of symptoms that lead them to withdraw from the experiment.

The simulator sickness results are important more for the consequences or effects that sickness can have on training. As Kolasinski (1995) has pointed out, sickness can decrease simulator use, compromise needed training through intrusive episodes, or lead to unsafe training conditions. Learning the "art" of producing VE systems that the majority of the population can adapt to and recover from is important, but learning the lawful causes of simulator sickness is the real goal. We need to be able to produce explicit rules that, when followed, preclude or eliminate interfering levels of VE sickness, and that can be easily followed during the design and development of VE training equipment and systems.

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Appendix A

Research Participant Information Questionnaire

Research Participant Information Questionnaire ID ___________

Please fill in the blank or circle the appropriate response.

1. What is your age? _____ years 2. What is your gender? female male

3. Are you currently in your usual state of good fitness? yes no

4. How many hours sleep did you get last night? _____ hours

    4a. Was it sufficient? yes no

5. Indicate all medications/substances you have used in the past 24 hours:

CIRCLE ALL THAT APPLY

0 - none

1 - sedatives or tranquilizers

2 - aspirin, Tylenol, other analgesics

3 - anti-histamines

4 - decongestants

5 - other (please list: ____)

6. Have you ever experienced motion or car sickness? yes no

7. How susceptible to motion or car sickness do you feel you are?

0	1	2	3	4	5	6	7
not susceptible	very mildly			average			very highly

8. Do you have a good sense of direction? yes no

9. How many hours per week do you use computers? _____ hours per week

10. My level of confidence in using computers is

1	2	3	4	5
low		average		high

11. I enjoy playing video games (home or arcade).

1	2	3	4	5
disagree		unsure		agree

12. I am _____ at playing video games.

1	2	3	4	5
bad		average		good

13. How many hours per week do you play video games? _____ hours per week

14. How many times in the last year have you experienced a virtual reality game or entertainment?

0 1 2 3 4 5 6 7 8 9 10 11 12+

15. Do you have a history of epilepsy or seizures? yes no

16. Do you have normal or corrected to normal 20/20 vision? yes no

17. Are you color blind? yes no